

8036-1-F

OPTICAL SENSING OF THE MOISTURE CONTENT IN FINE FOREST FUELS

Final Report

18 April 1966 Through 22 January 1967

CHARLES E. OLSON Jr.

May 1967



INFRARED AND OPTICAL SENSOR LABORATORY

Willow Run Laboratories
THE INSTITUTE OF SCIENCE AND TECHNOLOGY

Prepared for the U. S. Department of Agriculture
Forest Service, Washington, D. C.,
Contract 13-220

Sponsored by
Advanced Research Projects Agency
Remote Area Conflict
ARPA Order No. 818

Distribution of this document is unlimited.

NOTICES

Sponsorship. The work reported herein was conducted by the Willow Run Laboratories of the Institute of Science and Technology for the U. S. Department of Agriculture Forest Service, Washington, D. C., under Contract 13-220, and sponsored by the Advanced Research Projects Agency, Remote Area Conflict, ARPA Order No. 818. Contracts and grants to The University of Michigan for the support of sponsored research are administered through the Office of the Vice-President for Research.

Distribution. Initial distribution is indicated at the end of this document.

Final Disposition. After this document has served its purpose, it may be destroyed. Please do not return it to the Willow Run Laboratories.

8036-1-F

OPTICAL SENSING OF THE MOISTURE CONTENT IN FINE FOREST FUELS

Final Report

18 April 1966 Through 22 January 1967

CHARLES E. OLSON Jr.

Sponsored by
Advanced Research Projects Agency
Remote Area Conflict
ARPA Order No. 818

May 1967

Infrared and Optical Sensor Laboratory
Willow Run Laboratories
THE INSTITUTE OF SCIENCE AND TECHNOLOGY
THE UNIVERSITY OF MICHIGAN
Ann Arbor, Michigan

Distribution of this document is unlimited.

LIBRARY COPY
ROCKY MTN. FOREST & RANGE
EXPERIMENT STATION

WILLOW RUN LABORATORIES

FOREWORD

This report is one of several in a program to determine the feasibility of developing an imaging sensor which uses the spectral characteristics of a scene point to identify materials of interest or to enhance the contrast of selected objects. Multispectral imagery and video data for scenes of interest are generated from an airborne platform. Spectral reflectance or radiance of objects is measured in the laboratory or under field conditions. While multiband images are analyzed and interpreted using conventional photo-interpretation techniques, the spectral characteristics of targets and background objects are analyzed to determine how to electronically process spectral information from a scene in real time for improved remote sensing. The general goal of the program is to develop methods of improving and extending current aerial-survey capabilities; improvements are sought in the kinds and quantity of data obtainable and in the quality and economy of imagery interpretation.

This multispectral program was initiated and is being guided by Marvin R. Holter, Head of the Infrared and Optical Sensor Laboratory of Willow Run Laboratories, a unit of The University of Michigan's Institute of Science and Technology. Previous reports issued by the Infrared and Optical Sensor Laboratory under this and related programs are cited in the list of related reports which immediately follows.

WILLOW RUN LABORATORIES

RELATED REPORTS

COMPARATIVE MULTISPECTRAL SENSING (U), M. R. Holter and F. C. Polcyn, Report No. 2900-484-R, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, June 1965, AD 362 283 (CONFIDENTIAL).

DIURNAL AND SEASONAL VARIATIONS IN RADIATION OF OBJECTS AND BACK-
GROUNDS, 4.5-5.5- μ SPECTRAL REGION (U), L. D. Miller and R. Horvath,
Report No. 6400-32-T, Willow Run Laboratories of the Institute of Science and
Technology, The University of Michigan, Ann Arbor, June 1965, AD 362 620
(CONFIDENTIAL).

THE INVESTIGATION OF A METHOD FOR REMOTE DETECTION AND ANALYSIS
OF LIFE ON A PLANET, M. R. Holter, D. S. Lowe, and R. J. Shay, Report No.
6590-1-P, Institute of Science and Technology, The University of Michigan,
Ann Arbor, November 1964.

SPECTRUM MATCHING (U), R. E. Hamilton, Report No. 6400-18-T, Willow Run
Laboratories of the Institute of Science and Technology, The University of Mich-
igan, Ann Arbor, June 1965, AD 363 001 (CONFIDENTIAL).

TARGET SIGNATURE STUDY, INTERIM REPORT, VOLUME I: SURVEY (U), R. R.
Legault and T. Limperis, Report No. 5698-22-T(I), Institute of Science and
Technology, The University of Michigan, Ann Arbor, October 1964, AD 354 166
(CONFIDENTIAL).

TARGET SIGNATURE STUDY, INTERIM REPORT, VOLUME II: RECOMMENDA-
TIONS (U), R. R. Legault and T. Limperis, Report No. 5698-22-T(II), Institute
of Science and Technology, The University of Michigan, Ann Arbor, October 1964
(CONFIDENTIAL).

TARGET SIGNATURE STUDY, INTERIM REPORT, VOLUME III: POLARIZATION
(U), R. R. Legault and T. Limperis, Report No. 5698-22-T(III), Institute of Sci-
ence and Technology, The University of Michigan, Ann Arbor, October 1964,
AD 354 025 (CONFIDENTIAL).

TARGET SIGNATURE STUDY, INTERIM REPORT, VOLUME IV: BIBLIOGRAPHY
(ACOUSTIC, ULTRAVIOLET, VISIBLE, INFRARED, AND RADAR) (U), T. Lim-
peris and R. S. Gould, Report No. 5698-22-T(IV), Institute of Science and Tech-
nology, The University of Michigan, Ann Arbor, October 1964, AD 354 232
(SECRET).

TARGET SIGNATURE STUDY, INTERIM REPORT, VOLUME V: CATALOG OF
SPECTRAL REFERENCE DATA, R. R. Legault, R. S. Gould, and T. Limperis,
Report No. 5698-22-T(V), Institute of Science and Technology, The University
of Michigan, Ann Arbor, October 1964.

A COMPREHENSIVE TARGET-SIGNATURE MEASUREMENT PROGRAM, FIRST
INTERIM TECHNICAL REPORT, VOLUME I: TECHNICAL DISCUSSION (U),
Report No. 7251-3-P(I), Willow Run Laboratories of the Institute of Science and
Technology, The University of Michigan, Ann Arbor, December 1965 (CONFI-
DENTIAL).

A COMPREHENSIVE TARGET-SIGNATURE MEASUREMENT PROGRAM, SECOND
INTERIM TECHNICAL REPORT, VOLUME I: DATA PROCESSING, STORAGE,
AND ANALYSIS (U), Report No. 7251-9-P(I), Willow Run Laboratories of the
Institute of Science and Technology, The University of Michigan, Ann Arbor,
June 1966 (CONFIDENTIAL).

WILLOW RUN LABORATORIES

- A COMPREHENSIVE TARGET-SIGNATURE MEASUREMENT PROGRAM, SECOND INTERIM TECHNICAL REPORT, VOLUME II: MEASUREMENT IMPLEMENTATION (U), Report No. 7251-9-P(II), Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, June 1966 (CONFIDENTIAL).
- A COMPREHENSIVE TARGET-SIGNATURE MEASUREMENT PROGRAM, THIRD INTERIM TECHNICAL REPORT (U), Report No. 7251-15-P, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, February 1966 (CONFIDENTIAL).
- A COMPREHENSIVE TARGET-SIGNATURE MEASUREMENT PROGRAM, FINAL REPORT (U), T. Limperis, Report No. 7251-21-F, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, December 1966, AD 378 112 (CONFIDENTIAL).
- DISPERSIVE MULTISPECTRAL SCANNING: A FEASIBILITY STUDY, FINAL REPORT, J. Braithwaite, Report No. 7610-5-F, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, September 1966.
- AN INVESTIGATIVE STUDY OF A SPECTRUM-MATCHING IMAGING SYSTEM, FINAL REPORT, D. S. Lowe, J. Braithwaite, and V. L. Larrowe, Report No. 8201-1-F, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, October 1966.
- TARGET SIGNATURES ANALYSIS CENTER: DATA COMPILATION, D. G. Earing and J. A. Smith, Report No. 7850-2-B, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, July 1966, AD 489 968.
- INVESTIGATION OF SPECTRUM-MATCHING SENSING IN AGRICULTURE, SEMI-ANNUAL REPORT (U), F. C. Polcyn, Report 6590-7-P, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, in publication; Vol. I, UNCLASSIFIED; Vol. II, CONFIDENTIAL.

ABSTRACT

A preliminary study of the use of airborne remote sensors to determine the moisture content of fine forest fuels was performed. Laboratory and in situ measurements of light reflectance and energy emission from living and cut trees were obtained; the field data were collected during the 1966 growing season, while the laboratory measurements continued into early 1967. These data were then compared with multispectral imagery obtained over the test area in August and September 1966. For the first four days after cutting of the foliage, its reflectance increased at almost all wavelengths used, with the most significant increases occurring near 1.55, 2.05, and 2.50 μ . These increases seem directly related to decreasing moisture content, at least between moisture contents of 300% and 16% of the oven-dried weight of the foliar material. Radiometric data obtained were inconclusive, and problems with the multispectral sensors limited the validity of comparisons between the ground and airborne data. Nevertheless, it appears that multispectral imagery may provide useful information on the moisture content of fine forest fuels, and specific recommendations for additional work are included.

CONTENTS

Foreword	ii
List of Related Reports	iii
Abstract	v
List of Figures	viii
List of Tables	viii
1. Introduction	1
2. Experimental Approach and Results	2
2.1. Test Sites	4
2.2. Fuels in Standing-Tree Crowns	4
2.3. Fuels in Logging Slash	11
3. Discussion	17
4. Summary, Conclusions, and Recommendations	18
References	21
Distribution List	22

FIGURES

1. Spectral Reflectance Curves for a Sycamore Leaf with Varying Moisture Content	3
2. Panchromatic Aerial Photograph of the Primary Test Site Showing the Locations of the Six Slash Areas and of the Girdled Silver Maple and Cherry Trees	5
3. Simultaneous Panchromatic and Infrared Aerial Photographs of the Primary Test Site	5
4. Spectral Reflectance at 0.6 μ as a Function of Moisture Content for Five Leaves	9
5. Spectral Reflectance at 0.9 μ as a Function of Moisture Content for Six Leaves	9
6. Spectral Reflectance at 1.1 μ as a Function of Moisture Content for Six Leaves	9
7. Free-Hand Average Curves of Spectral Reflectance at 1.55 μ as a Function of Moisture Content for Two Species	10
8. Free-Hand Average Curves of Spectral Reflectance at 2.05 μ as a Function of Moisture Content for Two Species	10
9. Free-Hand Average Curves of Spectral Reflectance at 2.50 μ as a Function of Moisture Content for Two Species	10
10. Average Spectral Reflectance Curves for Cottonwood Leaves from Slash That Had Been Cut for Different Periods	14
11. Spectral Reflectance Curves for the Upper Surface of Four Rock-Elm Leaves Taken from Slash Area 3 at 1500 hr, 30 August 1966	14
12. Slash in Area 2 As Seen from Approximately 30 ft in the Air	15
13. Hi-Ranger and Radiometer Used To Obtain Data from Different Heights above Each Slash Area	16

TABLES

I. Daily Weather Data for the Primary Test Site During the Test Period	6
II. Summary of Measurements of Moisture Content of Leaves and Twigs from Six Slash Areas	13
III. Wavelength Bands for the Recommended Measurements	20

OPTICAL SENSING OF THE MOISTURE CONTENT IN FINE FOREST FUELS

**Final Report
18 April 1966 Through 22 January 1967**

¹ INTRODUCTION

The moisture content of fine forest fuels is one of the primary factors in the ignition of forest fires and their spread during initial stages. It is also an important factor in fire propagation during high-intensity phases of major fires, when transport of discreet ignition points (burning embers) ahead of the fire front can result in new ignitions if such ignition points are deposited on dry enough fuels.

During the initial stages of a fire's buildup and throughout the life of a low-intensity fire, fine forest fuels such as twigs, foliage, and leaf litter are more important determinants of the rate of spread than are the heavier fuels in the coarser branches and tree boles. These fine fuels are found in brush and herbaceous understories, tree tops, and relatively fresh logging slash. Since their geometric arrangement in living plants almost always insures adequate oxygen for combustion, such fuels promote rapid spreading and flash fire whenever their moisture content drops below the critical point. The ignition probability for these fuels under natural conditions is essentially zero if fuel moisture is much above 30% [1]. However, since the moisture content responds quickly to changes in atmospheric conditions, significant differences may occur within relatively short distances [2].

Work by Weber [3] and Olson [4] suggests that currently available airborne multispectral reconnaissance techniques, including infrared scanning systems, can record data related to differences in the moisture content of foliage. This report describes a study of the possibilities of determining the moisture content of fine forest fuels using multispectral techniques and related remote sensors that can be operated from an airborne platform. This study was essentially a pilot project to determine whether or not further research in this area is justified. The primary objectives were, specifically,

- (1) To determine whether or not airborne remote sensors can consistently record differences in the moisture content of fine forest fuels
- (2) To begin determinations of the magnitude of differences in moisture content necessary to produce a dependable variation in the remote-sensor record

- (3) To begin an assessment of the physiological and structural factors that may control the energy relationships involved in remote sensing of moisture content and other plant variables

2

EXPERIMENTAL APPROACH AND RESULTS

Seldom do remote sensors directly observe the phenomena on which they are to provide information. For image-forming optical sensors (ultraviolet, visible, and infrared), the sensor output is a graphical display of spatial variation of a scene's brightness. From information conveyed by such factors as tone, shape, texture, and environment, an image interpreter deduces information about the object under investigation. In evaluating the feasibility of remote detection of the moisture content of fine forest fuels, one must determine whether or not there is a change in an observable property which is characteristic of or uniquely related to moisture content.

In the optical region, some of the characteristics which may be detected using the radiation reflected or emitted from vegetation are

- (1) Spectral variations arising from changes in pigmentation (color)
- (2) Spectral variations arising from changes in water content (infrared absorption beyond 1.5μ)
- (3) Reflectance changes resulting from changes in the internal geometry of leaf tissues caused by variations in turgidity
- (4) Temperature changes arising from changes in transpiration and thermal mass

Figure 1 shows the diffuse spectral reflectance of a leaf with varying moisture content. To detect all of the observable characteristics listed requires sensor operation in several bands of the optical spectrum. Pigmentation effects occur predominately in the visible region, scattering phenomena in the near infrared, and thermal changes in the intermediate and far infrared. Which wavelength region or regions best exhibit detectable changes associated with moisture content or moisture stress in plant foliage has not yet been determined.

Experiments using laboratory and field instrumentation available at The University of Michigan were planned to cover three situations. The first involved root pruning of standing trees to induce moisture stress. As discussed in sections 2.1 and 2.2, this part of the investigation was abandoned because of unusual moisture conditions at the test site in July and August 1966. The second situation involved repeated measurements made on leaves plucked from

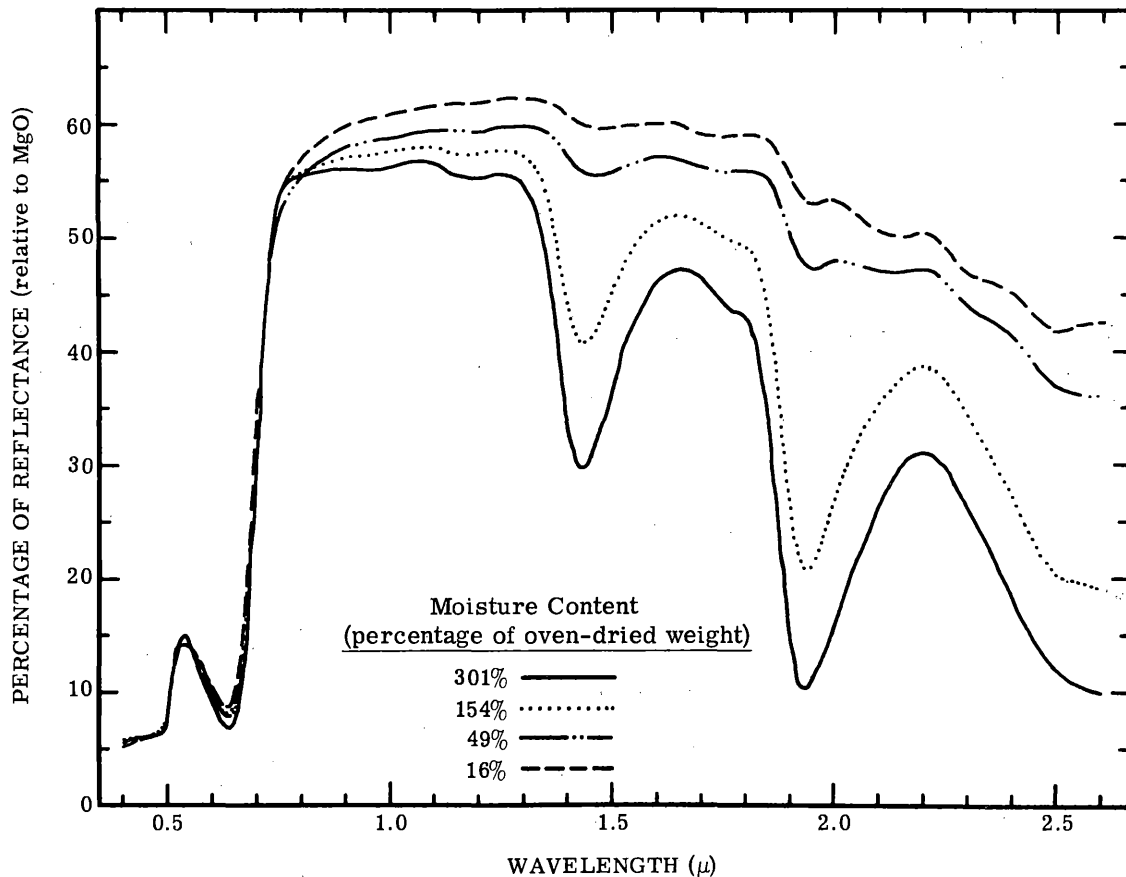


FIGURE 1. SPECTRAL REFLECTANCE CURVES FOR A SYCAMORE LEAF WITH VARYING MOISTURE CONTENT. The leaf was allowed to air dry between successive measurements.

living trees and allowed to dry between measurements. While this situation may not have entirely simulated a more slowly induced moisture stress in intact plants, it is felt that the measurements did provide the best evidence obtainable on the spectral bands most suited for detecting changes in moisture content observable in reflected sunlight. These measurements are reported in section 2.2.

The third method of obtaining differences in the moisture content of fine fuels was to create areas of slash by cutting living trees and placing the cut branches in piles at least 20 ft square. Moisture-content and spectral-reflectance measurements were made on sampled leaves; thermal radiometric measurements were made of the piles and their background; and airborne scanners capable of resolving targets smaller than 20 ft square were operated over the area. However, as indicated in section 2.3,

WILLOW RUN LABORATORIES

- (1) The great variations observed in the small samples obtainable from any one slash area made the observations inconclusive.
- (2) The optical filters and noise level in the infrared channels of the multispectral scanners resulted in imagery which was questionable.

2.1. TEST SITES

A wooded area immediately adjacent to the Willow Run Airport near Ypsilanti, Michigan, was selected as the primary test site. This area is owned by The University of Michigan and is the site of a micrometeorology study already using instrumentation which included continuously recording devices for monitoring air temperature, dew point, wind velocity, total incident radiation, and net radiation received near ground level and at the top of the forest canopy. Aerial photographs of this site are shown in figures 2 and 3. The University of Michigan's Saginaw Forest, just west of Ann Arbor, was selected as a supplementary test site when the water table was discovered close to the surface at the primary site. The high water table would have made it difficult to keep sample trees under drought conditions during the study.

Neither test site proved completely satisfactory. Heavy rains prevented drought conditions from developing at the Saginaw Forest site, and because of malfunctions in the recording circuitry, meteorologic data collected at the airport site have not yet been decoded. Scattered meteorologic observations were made at the airport site by field personnel gathering other data, and table I contains a combination of these and data from the U. S. Weather Bureau station at Willow Run Airport for the test period.

2.2. FUELS IN STANDING-TREE CROWNS

Twelve trees in a 58-year-old plantation of red oak (Quercus rubra L.) within the Saginaw Forest property were selected as sample trees. All twelve were in the dominant or codominant crown classes and had crown diameters in excess of 20 ft. Six of the trees had been root pruned during the fall of 1965 and their residual root systems covered with low, waterproof sheds in the spring of 1966. The six other trees were artificially irrigated throughout the summer of 1966. Standard dendrometer bands were placed on each of the twelve trees, and radial expansion of the tree boles was determined at weekly intervals during the growing season. A neutron probe was used to determine moisture content of the soil; measurements of this were made under each waterproof shed and near the irrigated trees at least once each week during this period. Moisture stress in the tree foliage was ascertained using the method described by Shardaikov [5], and leaf moisture content was determined gravimetrically.

No differences between soil moisture content under and outside of the sheds were detected with the neutron probe after 12 July, when 2.67 in. of rain were recorded in a 24-hr period by

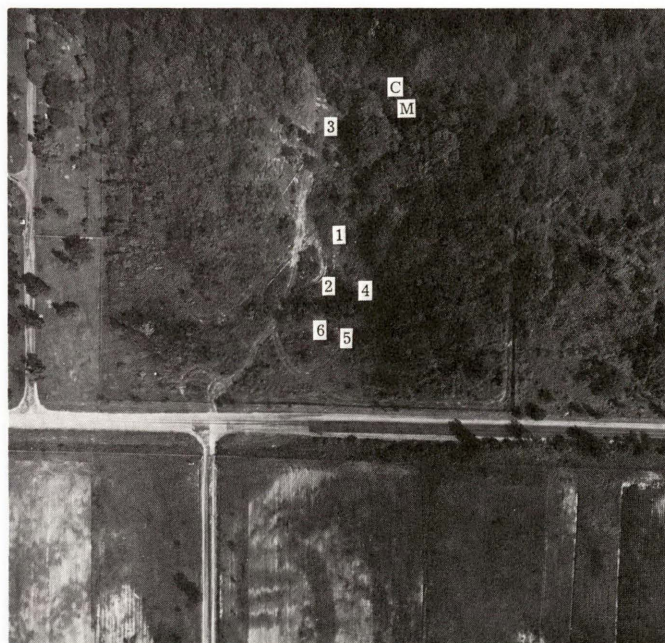


FIGURE 2. PANCHROMATIC AERIAL PHOTOGRAPH OF THE PRIMARY TEST SITE SHOWING THE LOCATIONS OF THE SIX SLASH AREAS AND OF THE GIRDLED SILVER MAPLE (M) AND CHERRY (C) TREES



(a) Panchromatic



(b) Infrared

FIGURE 3. SIMULTANEOUS PANCHROMATIC AND INFRARED AERIAL PHOTOGRAPHS OF THE PRIMARY TEST SITE. The photographs were obtained at approximately 1300 hr on 1 September 1966. Slash areas 1, 2, 3, and 4 could be discerned in the original photographs, but areas 3 and 4 would not be detected without prior knowledge of their location.

WILLOW RUN LABORATORIES

TABLE I. DAILY WEATHER DATA FOR THE PRIMARY TEST SITE DURING THE TEST PERIOD

Date	U. S. Weather Bureau, Willow Run Airport			Observations of Field Crews			
	Temperature (°F)		24-hr Precipitation (in.)	Time of Day	Surface Temperature (°F)	Relative Humidity (%)	Additional Remarks
	Max.	Min.					
August 14	71	61	0.10				
15	83	62	0.05				
16	78	63	1.36				
17	82	56		2000 2100	70 66	85 93	
18	86	61	0.15				
19	77	53					
20	76	48					
21	77	57	0.56				
22	80	60	0.32				
23	69	54					
24	72	50		1100 1150	69 75	63 53	
25	72	50	Trace	0830 1300	65 71	85 55	100% cloud cover at 12,000 ft; surface wind from SW at 6 knots; rain began at 1530
26	83	54					
27	85	58					
28	85	58					
29	85	63					
30	85	58		0920 1020 1330 1500	78 86 88 91	71 50 48 46	Surface vegetation still wet from dew. 100% cloud cover at 12,000 ft; surface wind from SW at 10 knots
31	87	59					
September 1	86	63	Trace	1300	82		Hazy with 40% cloud cover at 4500 ft; surface wind from W at 8 knots

the U. S. Weather Bureau at Willow Run Airport. This rain produced saturated soil conditions, and lateral flow of soil-water under the sheds probably occurred. During late July and early August, both the moisture stress and moisture content of individual leaves varied more within single trees than between trees subjected to different treatments. It is possible that the root-pruned trees had produced enough new roots during the early part of the growing season to permit prompt replenishment of transpired water, at least when soil moisture was readily available. After another heavy rain, 1.36 in. on 16 August, which produced saturated soil conditions, the Saginaw Forest test site was abandoned and subsequent efforts concentrated at the primary test site.

On 19 August a large silver maple (Acer saccharinum L.) and a large black cherry (Prunus serotina Ehrh.) were girdled at the primary test site. Both girdles were cut with a chain saw and penetrated into heart wood at all points around the circumference of the tree. High moisture stress was expected to develop quickly in both trees, but no differences between girdled and ungirdled trees of the same species on the same site were observed. The moisture content of leaves from both trees remained above 200% of the leaf's oven-dried weight (as determined after the completion of measurements on the leaf) for eight days following the girdling, and measurements were subsequently discontinued on the afternoon of 29 August. However, between the time when the measurements were discontinued and the afternoon of 1 September, leaves on the black cherry wilted and turned brown. The foliage of the silver maple showed no visible effects of girdling even as late as 15 September. Despite this obvious difference between the trees, neither of them produced a tone difference that could be detected in imagery obtained in any wavelength band during midafternoon on 30 August and 1 September.

On 17 August a series of measurements of light reflectance from individual leaves was begun. These measurements were continued into January 1967 with leaves from seedlings one and two years old which were grown at The University of Michigan's Botanical Gardens for other studies. The leaves picked from living trees at the primary test site were weighed to the nearest tenth of a milligram immediately after picking, then sealed in Saran wrap and kept out of the sun while being transported to the mobile spectrophotometer laboratory [6]. All of these leaves reached the air-conditioned laboratory within ten minutes after they had been picked. As soon as a leaf was unwrapped, it was weighed again and then placed in the Beckman DK-2a spectrophotometer used to obtain the light-reflectance measurements. Leaves from the seedlings were similarly handled except that wrapping them in Saran wrap was unnecessary since whole plants were moved to the laboratory and the leaves picked just before the measurements began.

After reflectance curves were obtained for both the upper and lower surfaces of a leaf, it was weighed once more, allowed to air dry for 15 to 20 minutes and then reweighed and placed in the spectrophotometer as before. In this way a sequence of light-reflectance measurements was obtained at decreasing moisture contents. After the series of measurements on any one leaf was completed, the leaf was oven dried at 125°F overnight, and, as indicated above, the moisture content of the leaf at the time of any weighing was computed as a percentage of its oven-dried weight. The moisture content at the time of any reflectance measurement was assumed to be the average of the moisture content immediately before and after the reflectance measurements were obtained.

The Beckman DK-2a spectrophotometer used provides a continuous curve of light reflectance versus wavelength. It operates in the wavelength range from 2.6 to 0.2 μ , but requires three separate arrangements, with different detectors and/or light sources, to handle this entire range. Early data indicated no significant differences in reflectance at wavelengths shorter than 0.5 μ , and previous, but unpublished, work indicated that appreciable drying of samples occurs during the time required to obtain reflectance data over the wavelength range from 2.6 to 0.5 μ . For these reasons, the collection of light-reflectance data was concentrated between wavelengths of 1.2 and 0.5 μ , with some additional supplementary data obtained for the 2.6- to 1.0- μ region. The time required to obtain reflectance curves from both the upper and lower surfaces of one leaf was 12 minutes for the 1.2- to 0.5- μ region and 20 minutes for the 2.6- to 1.0- μ region.

The moisture content of leaves from living trees at the time of picking was usually greater than 300% of their oven-dried weight and seldom dropped below 200% of that weight. Except for three leaves from a suppressed rock elm (Ulmus thomasii Sarg.) that had already begun a visible "Fall color change" and two leaves from a yellow poplar (Liriodendron tulipifera L.) seedling the leaf margins of which had begun to curl and turn brown from lack of water, the moisture content of leaves freshly picked from living trees was never observed to be less than 135% of their oven-dried weight. As the leaves dried, moisture contents lower than 10% were obtained.

Within the range of moisture content sampled, variations in light reflectance were greater between and within species than between moisture contents for all wavelengths between 1.2 and 0.5 μ . Figures 4, 5, and 6 show the spectral reflectance of several leaves as a function of moisture content at wavelengths of 0.6, 0.9, and 1.1 μ , respectively. At longer wavelengths, the reflectance appears to increase almost linearly as moisture content decreases, although differences between species were observed. Typical data for such changes in reflectance as a function of moisture content are shown in figures 7, 8, and 9 for wavelengths of 1.55, 2.05, and 2.50 μ , respectively. The data for these figures were obtained from eight or more leaves of each species that were allowed to air dry between successive measurements. The reflectance differences shown between leaves at 200% moisture content and leaves at 50% moisture content are large enough to be detectable by remote sensors operating in the 1.5- to 1.7- μ and 2.0- to 2.5- μ bands. However, changes in moisture content of this magnitude seldom occur abruptly in nature. Natural variation in backgrounds made up of different tree species would undoubtedly mask small differences in reflectance which result from moisture content.

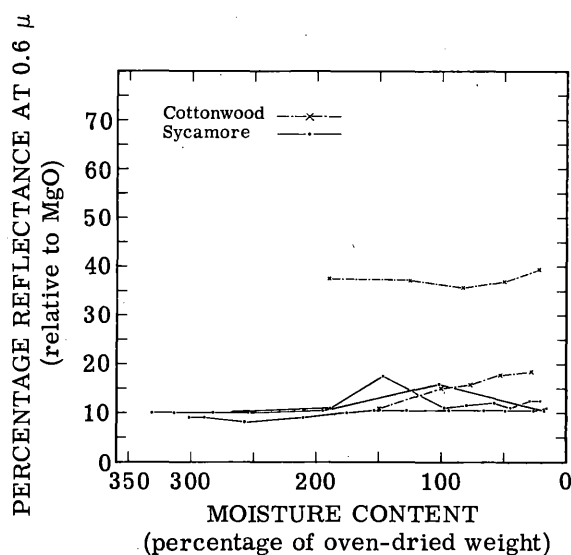


FIGURE 4. SPECTRAL REFLECTANCE AT 0.6μ AS A FUNCTION OF MOISTURE CONTENT FOR FIVE LEAVES

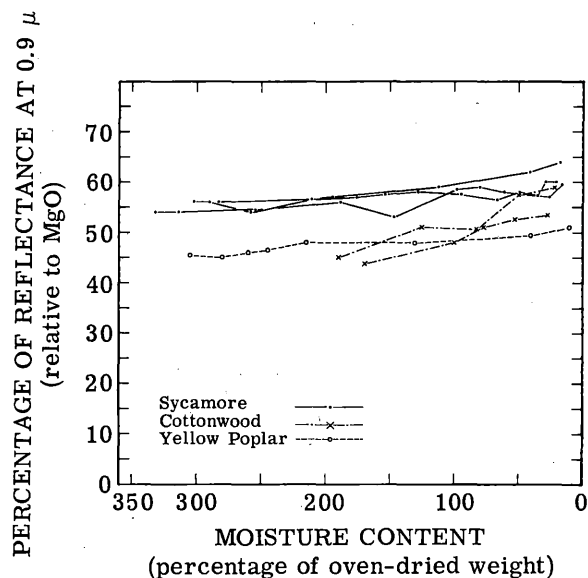


FIGURE 5. SPECTRAL REFLECTANCE AT 0.9μ AS A FUNCTION OF MOISTURE CONTENT FOR SIX LEAVES

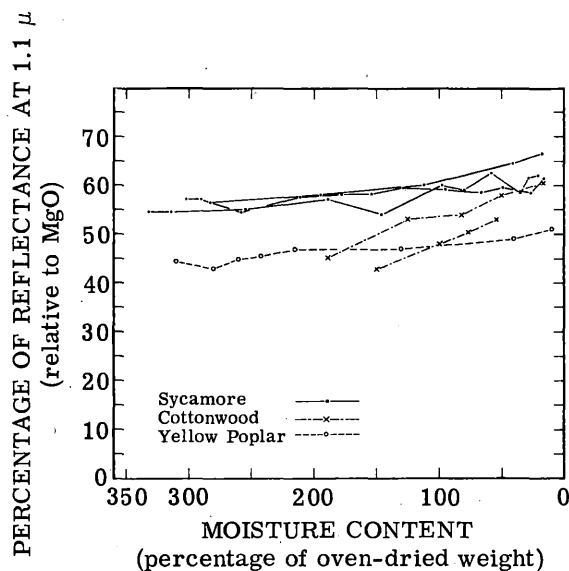


FIGURE 6. SPECTRAL REFLECTANCE AT 1.1μ AS A FUNCTION OF MOISTURE CONTENT FOR SIX LEAVES

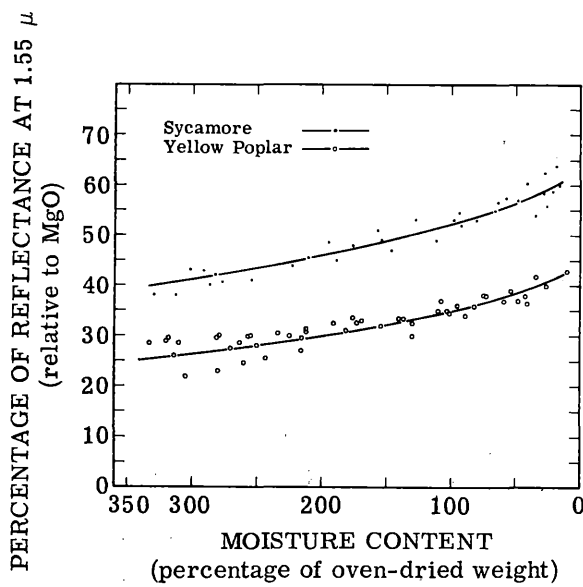


FIGURE 7. FREE-HAND AVERAGE CURVES OF SPECTRAL REFLECTANCE AT 1.55μ AS A FUNCTION OF MOISTURE CONTENT FOR TWO SPECIES

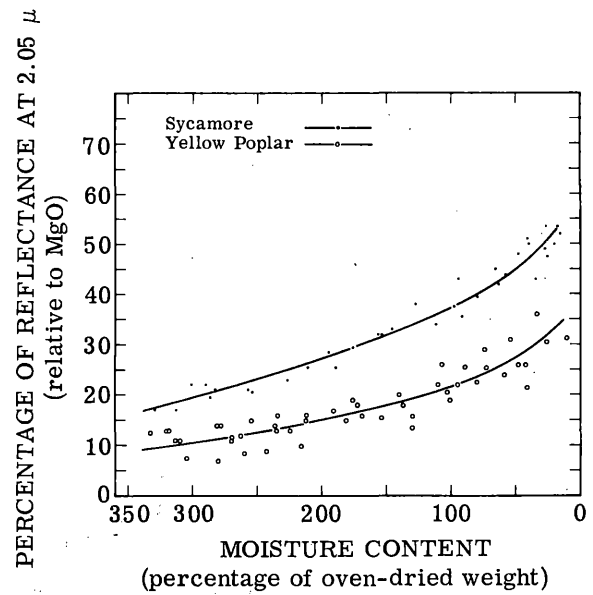


FIGURE 8. FREE-HAND AVERAGE CURVES OF SPECTRAL REFLECTANCE AT 2.05μ AS A FUNCTION OF MOISTURE CONTENT FOR TWO SPECIES

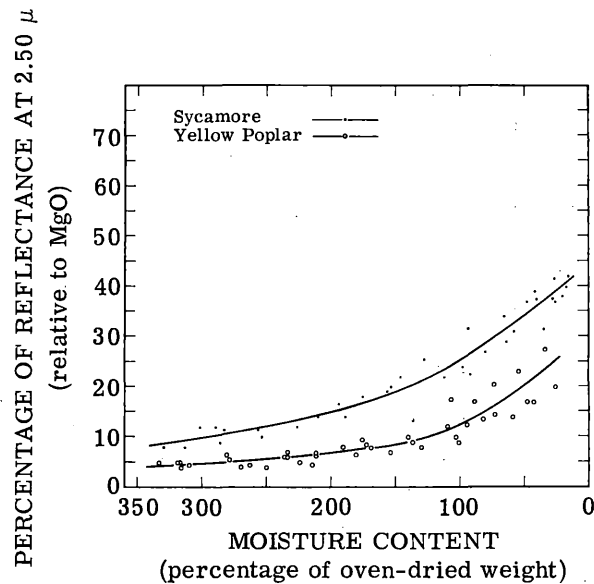


FIGURE 9. FREE-HAND AVERAGE CURVES OF SPECTRAL REFLECTANCE AT 2.50μ AS A FUNCTION OF MOISTURE CONTENT FOR TWO SPECIES

2.3. FUELS IN LOGGING SLASH

Beginning in May 1966, a series of slash areas were created by felling and/or pruning live trees. Beech (Fagus grandifolia Ehrh.), black cherry (Prunus serotina Ehrh.), cottonwood (Populus deltoides Bartr.), rock elm (Ulmus thomasii Sarg.), and sycamore (Platanus occidentalis L.) were the primary species used. The slash was supported two to three feet off of the ground in four areas to provide air circulation under as well as across the cut material. During the weekend of 16 and 17 July, three of the four areas of suspended slash were collapsed by trespassers. One of these areas was still useable as an area of scattered slash, but the other two had to be abandoned. Subsequent measurements were confined to the remaining area of suspended slash, the collapsed, but useable, area, and four areas of relatively fresh slash prepared from 17 August through 30 August. In these last four areas, the limbs of the cut trees were scattered on the ground to provide a reasonably uniform cover, with the cut foliage obscuring 70% or more of the ground area beneath the slash. All the slash areas were located at the primary test site and were at least 20 ft × 20 ft in size.

Moisture content for samples drawn from each slash area was determined gravimetrically. Foliage and small twigs (up to 0.25 in. in diameter) were sampled separately, and samples were collected at approximately 9 am and 2 pm each day. Standard soil-moisture cans were used as containers, and each sample was a composite of leaves or twigs from several different locations in the slash area. At each sampling period, enough leaves were taken to fill a can or enough twigs taken to three-quarters fill a can.

Moisture-content data obtained from the suspended slash areas prior to mid-June indicated that both foliage and twigs dried rapidly and that their moisture content varied almost directly with changes in atmospheric conditions within six days after cutting. Therefore, measurements were discontinued until 19 August, approximately two weeks before the airborne work was scheduled to begin. The preparation of slash areas was then also discontinued until two weeks before the start of airborne work, when the four additional areas already described were prepared to provide a range of fuel dryness at the time of the flights. The last slash area was prepared only three hours prior to the first series of flights.

On 20 August, a plot 50 × 50 ft in a brushy area at the primary test site was sprayed with a water solution of 2, 4-D/2, 4, 5-T prepared in accord with the manufacturer's recommendations for killing woody brush. Hard rains that began early on 21 August may have washed this poison off the sprayed plants and account for the complete failure of this treatment. No leaf curl, browning, or other visible symptoms of the poison were observed at any time.

On 17 August, ground measurements of the moisture content of foliage and twig samples from each slash area were resumed on the schedule and using the methods previously described.

WILLOW RUN LABORATORIES

These measurements continued until the end of the flight program and are summarized in table II. Light-reflectance measurements of foliage samples were obtained using the Beckman DK-2a spectrophotometer also previously described. Reflectance measurements in the 1.2- to 0.5- μ range were obtained for leaves from each slash area before the first flight and again at the time of the flight of 30 August. A deliberate attempt was made to select leaves representative of the visible variations in leaves from cut material in each area. After six leaves from each area were selected in the field, they were wrapped in Saran wrap and taken to the mobile laboratory where the reflectance of both the upper and lower surfaces of four of the six was measured. Selecting six leaves in the field, though only four were to be used for the reflectance measurements, permitted rejection of those leaves so badly curled that they shattered when an attempt was made to uncurl them and place them in the spectrophotometer.

Changes in reflectance from the cut foliage were observed as a function of time at almost all wavelengths from 1.2 to 0.5 μ . These changes are graphically portrayed by the reflectance measurements made on the afternoon of 30 August for leaves from slash areas 4, 5, and 6. Trees in these areas had all been cut from a single stand of cottonwood on 18, 26, or 30 August and had dried to moisture contents of 4.2, 8.7, and 41.2%, respectively, by the time of the measurements. Each of the reflectance curves in figure 10 is the average of four curves obtained from different leaves taken from the indicated slash areas. An average reflectance curve for leaves taken from slash area 6 immediately after the trees were cut on the morning of 30 August is included. Many of the differences between the curve for freshly cut material and that for the leaves from area 4, which had been cut 12 days earlier, are great enough to be detected. All six slash areas were discernible in the airborne data obtained in the 0.72- to 0.80- μ and 0.80- to 1.0- μ bands, and several of these areas were identifiable in other bands as well. However, with the exception of area 1, in which the slash was supported above the ground, none of the slash areas would have been detected in the imagery from any one band without prior knowledge of their location.

The data obtained on leaves from any one slash area varied greatly. Reflectance curves for four rock-elm leaves from slash area 3 are shown in figure 11. Even though the trees were cut on 17 August, some of the leaves were still green on 30 August. Furthermore, photographs obtained from varying heights above the slash showed that wilting of the foliage reduced the percentage of ground obscured by the slash in areas 3, 4, 5, and 6 from the 70% planned to 35 to 55%. Thus, the fields of view of the airborne line scanners were not restricted to slash, but were integrating radiation from slash, soil, and surface vegetation. Enough herbaceous vegetation had grown up through the slash in area 2 to largely obscure the slash at the time of the flight operations (see fig. 12).

TABLE II. SUMMARY OF MEASUREMENTS OF MOISTURE CONTENT OF LEAVES AND TWIGS FROM SIX SLASH AREAS

Slash Area	Date Cut	Tree Species	Slash Position	Moisture Content (%)																				
				19 Aug.		20 Aug.		22 Aug.		23 Aug.		24 Aug.		25 Aug.		26 Aug.		29 Aug.		30 Aug.		1 Sept.		
				am	pm	am	pm	am	pm	am	pm	am	pm	am	pm	am	pm	am	pm	am	pm	am	pm	
Leaves	1	11 May	Beech Black Cherry	Raised 3 ft off ground	16.7	4.9	--	6.1	97.8	16.0	25.0	17.5	16.7	17.6	79.6	10.0	29.8	10.0	17.4	13.2	44.9	11.5	--	11.4
	2	17 May	Cottonwood Black Cherry	On ground	12.8	7.7	--	7.0	227.0	--	18.6	--	13.5	8.0	44.3	10.5	14.3	8.3	13.2	11.1	15.2	--	--	10.2
	3	17 Aug. (pm)	Rock Elm Sycamore	On ground	42.3	39.7	--	28.0	147.4	64.9	89.1	40.6	60.0	39.2	100.0	39.0	10.5	29.6	38.1	18.6	69.6	17.2	--	13.7
	4	18 Aug. (pm)	Cottonwood	On ground	132.7	36.2	--	16.5	190.9	113.8	71.6	19.3	37.0	20.8	83.1	14.6	34.4	16.9	20.7	9.0	47.8	4.2	--	10.0
	5	26 Aug. (am)	Cottonwood	On ground	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	49.5	8.7	--	7.1
	6	30 Aug. (am)	Cottonwood	On ground	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	41.2	--	9.9
Twigs	1	11 May	Beech Black Cherry	Raised 3 ft off ground	22.0	21.1	--	28.2	28.0	28.3	32.7	25.0	25.0	22.2	25.0	27.4	23.0	21.2	27.0	25.5	25.5	21.6	--	20.7
	2	17 May	Cottonwood Black Cherry	On ground	21.2	19.5	--	22.2	35.8	--	26.0	--	25.4	22.8	32.7	21.0	20.6	15.7	33.2	26.1	20.3	--	--	20.5
	3	17 Aug. (pm)	Rock Elm Sycamore	On ground	56.6	48.8	--	42.0	65.2	--	51.3	--	57.1	60.5	52.1	42.1	58.2	53.1	43.6	49.2	51.1	42.3	--	36.2
	4	18 Aug (pm)	Cottonwood	On ground	64.9	55.6	--	52.0	59.1	60.6	54.7	55.8	58.2	55.7	56.5	51.8	51.6	55.5	44.8	52.1	49.3	48.4	--	41.9
	5	29 Aug. (am)	Cottonwood	On ground	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	54.2	45.1	--	41.8
	6	30 Aug. (am)	Cottonwood	On ground	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	56.0	--	41.9

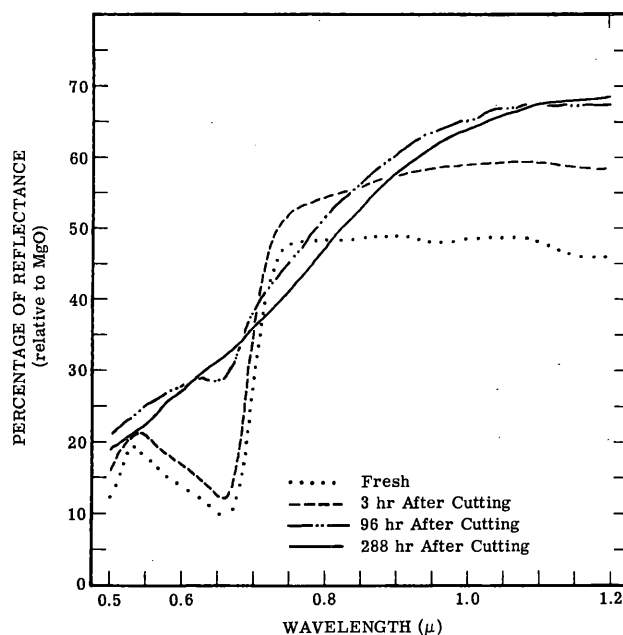


FIGURE 10. AVERAGE SPECTRAL REFLECTANCE CURVES FOR COTTONWOOD LEAVES FROM SLASH THAT HAD BEEN CUT FOR DIFFERENT PERIODS. Each curve shown is an average of four curves, and all curves were obtained on 30 August 1966.

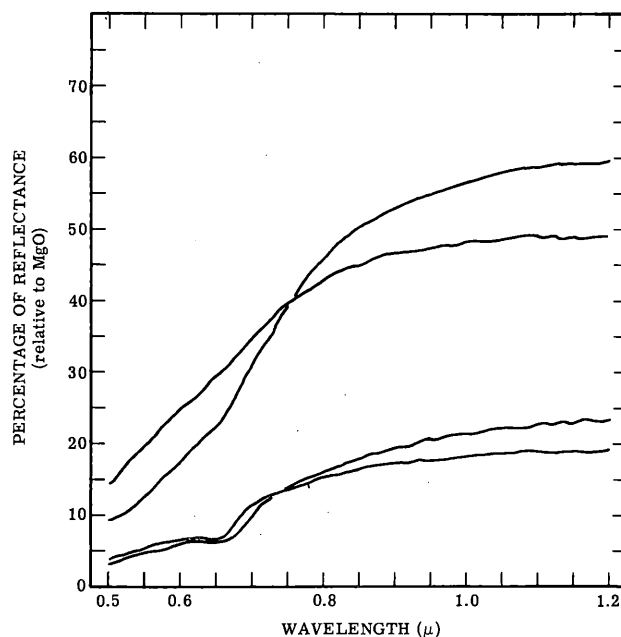


FIGURE 11. SPECTRAL REFLECTANCE CURVES FOR THE UPPER SURFACE OF FOUR ROCK-ELM LEAVES TAKEN FROM SLASH AREA 3 AT 1500 hr, 30 AUGUST 1966



FIGURE 12. SLASH IN AREA 2 AS SEEN FROM APPROXIMATELY 30 ft IN THE AIR. This photograph was taken from the Hi-Ranger on 25 August 1966 and is from directly over the slash. A color print of this photograph is included in a pocket inside the back cover of this report.

Reflectance measurements for the wavelength region between 2.6 and 1.0 μ were obtained subsequent to the flight program. Both the 1.2- to 0.5- μ and the 2.6- to 1.0- μ measurements could not be obtained at the time of the flights because the spectroreflectometer cannot be operated that rapidly. The data shown in figures 7, 8, and 9 are considered applicable to fuels in slash. The differences shown in these figures are great enough so that they should be detectable in imagery from line-scanning systems filtered to the 1.5- to 1.7- μ and 2.0- to 2.2- μ bands. However, none of the slash areas were detectable in imagery obtained in these bands during the 30 August or 1 September flights, and both the optical filters and the noise level in the infrared channels of the multispectral scanners are believed to have contributed to this.

A Stoll-Hardy HL-4 radiometer filtered to the 8- to 14- μ range was used to obtain radiometric data on each sample area and adjacent backgrounds at the time of the flights. A mobile, hydraulic boom (Hi-Ranger) was used to position this radiometer at various elevations from 3 to 50 ft above each slash area (see fig. 13). Additional data were obtained from individual leaves picked from live trees and allowed to air dry in the sun between radiometer measurements.



FIGURE 13. HI-RANGER AND RADIOMETER USED TO OBTAIN DATA FROM DIFFERENT HEIGHTS ABOVE EACH SLASH AREA. The Hi-Ranger and Stoll-Hardy radiometer are shown positioned approximately 40 ft above slash area 2.

Data obtained with the radiometer were apparent temperatures and were the integrated results of differences in emissivity as well as actual temperature differences of materials in all areas within the instrument's 20° field of view. Examination of these data has not revealed any positive relationship between moisture content and apparent temperature of the targets versus the adjacent backgrounds. It is believed that the relatively small thermal mass of foliage materials causes fluctuations in the apparent temperature of both living and cut foliage to depend more on local microclimate than on moisture content. Reversals of temperature contrasts between targets and backgrounds were observed to occur rapidly whenever the velocity of surface winds changed or clouds passed overhead. As already mentioned, the radiometer data proved inconclusive, although it was consistently observed that undisturbed trees (including cottonwood, sycamore, beech, and black cherry) were 6 to 8°C "cooler" during the day than surface vegetation and slash. Bare soil surfaces of roads and trails were consistently the "warmest" targets in the area.

3 DISCUSSION

Differences in spectral reflectance associated with differences in moisture content of fine forest fuels were observed in the laboratory at almost all wavelengths from 2.6 to 0.5 μ and seem large enough to permit detection with several types of remote sensors. Standard aerial cameras can detect the larger differences observed between 0.6 and 0.7 μ and between 0.7 and 1.0 μ . The success of several earlier investigations in detecting dead and dying trees in aerial photographs taken on panchromatic film through a Wratten 25 filter and on infrared film through a Wratten 89B filter attest to this. However, neither previous work nor this study has produced evidence that differences in the moisture content of fine forest fuels can be determined quantitatively, except in the grossest sense, from aerial photographs. It appears that in any wavelength band recorded by camera systems, the light reflectance from foliage having a moisture content of 50% (and too wet to sustain combustion) is not greatly different from the reflectance from foliage having a moisture content of 16% (and dry enough to burn readily). Nevertheless, this does not mean that the moisture content of fine fuels cannot be determined from spectral information in the 0.5- to 1.0- μ range. Analysis of imagery obtained in several narrow wavelength bands simultaneously has permitted identification of different crop types in situations where these identifications could not be made from information in any single wavelength band [7].

Multispectral imagery can be obtained with multilens cameras filtered so that each lens records a different wavelength band. Band selection with such camera systems is sharply limited by the spectral sensitivity of available photographic emulsions, the bandwidths obtainable with available filters, and the relatively low amount of energy available and the resultingly long exposure times needed when very narrow wavelength bands are photographically recorded. Multispectral imagery can also be obtained with line-scanning systems such as the multi-channel scanners of the Infrared and Optical Sensor Laboratory of Willow Run Laboratories. These systems, which record the data in electronic form, can record energy over a much wider range of wavelengths. The electronic signals produced are raw spectra of each scene point and are amenable to real-time electronic processing. Thus, it appears feasible to automatically detect small differences in the spectral reflectance of vegetation with such systems.

One of the simplest techniques for multispectral data processing amounts to an analysis of covariances in an n-dimensional array, where n is the number of spectral bands of operation. Such analysis can be extremely valuable when variations in one attribute, reflectance at a given wavelength for instance, are only partially correlated with variations in other attributes. The curves in figure 1 suggest that light reflectance varies with moisture content in this fashion.

The changes observed in the visible spectrum result from changes in foliage pigmentation (color) as the leaves dried, while the changes observed in the infrared spectrum are related to other factors.

One of these last-mentioned factors is the internal geometry of the leaf tissues, for cell shapes change as unreplenished water loss produces moisture stress. Several attempts were made to observe differences in cell shapes in leaves that had developed under different degrees of moisture stress. No meaningful results were obtained because no method was found to observe the shape of cells inside a leaf without disrupting the leaf metabolism and thereby invalidating the observations. However, on the basis of what is known about cell walls and cell behavior, changes in shape must occur as the cells go from fully turgid to flaccid states.

Analysis of data collected during this study has indicated that comparative interpretation of imagery obtained simultaneously in the 0.6- to 0.65- μ , 0.85- to 0.95- μ , 1.0- to 1.2- μ , 1.5- to 1.7- μ , and 2.0- to 2.2- μ bands may permit determination of the moisture content of fine forest fuels from multispectral imagery produced by airborne scanners. Further investigation is needed and may reveal that moisture-content determinations can be made from imagery obtained in fewer than these five bands.

While the laboratory spectra of leaves show a change in diffuse reflectance as a function of moisture content, it is difficult to predict with a high degree of certainty whether or not an operational system to remotely sense a condition of moisture stress can be produced. Extrapolation of the laboratory data to the operational airborne case is limited by the following factors:

- (1) Moisture stress can vary among leaves from a single tree.
- (2) An airborne sensor views a number of leaves simultaneously in a geometry where some of the leaves are in shade and some in full sun.

Because of these limitations, it would be desirable to make field spectral measurements with an instrument having a field of view which would encompass a minimum area of one square foot.

4

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Ground measurements of reflectance and emittance from fine forest fuels with different moisture contents were made and compared with remote sensor imagery obtained concurrently in several narrow wavelength bands. The ground data indicate that the differences in reflect-

ance and/or emittance were sufficiently large in several bands for the moisture-content differences to be detectable in airborne-scanner imagery obtained in those bands. Despite poor filter performance and excessive noise in the line scanners used, several test targets were detected in the imagery. However, variations in the strength of signals from natural backgrounds were so large that only one target would have been detected without prior knowledge of the target locations.

The objective of this study was to indicate whether determination of moisture content in fine forest fuels by optical remote-sensing techniques warranted further and more detailed investigation. While the data gathered were not extensive enough to be conclusive, five tentative conclusions seem justified:

(1) At all wavelengths between 2.6 and 0.9 μ , the reflectance from tree foliage increases as the foliage's moisture content decreases during the first twelve hours after cutting, at least for the broad-leaved species studied. At shorter wavelengths, differences between species prevent generalizations from the data available.

(2) When the differences in moisture content are large, differences in the reflectance and emittance from foliage are great enough to be detectable by airborne line-scanning systems, particularly in the 0.8- to 1.2- μ , 1.5- to 1.7- μ , and 2.0- to 2.2- μ bands.

(3) Reflectance and emittance vary with species as well as with changes in moisture content, and brightness differences between species may be greater, particularly in the visible and photographic infrared regions, than those resulting from different moisture contents.

(4) Natural backgrounds vary considerably in reflectance and emittance, and these natural variations can mask reflectance differences in any one wavelength band which are caused by moisture content alone.

(5) The data collected during this study neither prove nor disprove that airborne remote sensors can be used to determine the moisture content of fine forest fuels.

Reflectance or emittance observations in a single wavelength band do not hold great promise for "unique" detection. Laboratory spectral data suggest, however, that simultaneous observations in several spectral bands may offer a basis for determining the moisture content of fine forest fuels in broad-leaved trees. Successful implementation of this technique requires further studies. Detection of stress in a uniform stand should be possible with a minimum of further research, but detection of stress in mixed stands will require more extensive data collection and analysis.

On the basis of these observations and conclusions, a program of field spectral measurements and analysis is recommended. The measurements would require special instrumentation

WILLOW RUN LABORATORIES

to provide a field of view permitting integration of radiations from a target area of one square foot. These quantitative measurements could be made with a ground-based spectrophotometer or a modified airborne scanner operating in a minimum of six wavelength bands, as indicated in table III. The recommended location of the first five of these bands is based on the spectral reflectance measurements made in this study and on atmospheric transmission.

TABLE III. WAVELENGTH BANDS FOR THE
RECOMMENDED MEASUREMENTS

<u>Band</u>	<u>Observable</u>
0.60 to 0.65 μ	Pigmentation
0.85 to 0.95 μ	Pigmentation and internal scattering
1.0 to 1.2 μ	Internal scattering
1.5 to 1.7 μ	Internal scattering and moisture content
2.0 to 2.2 μ	Internal scattering and moisture content
4.5 to 5.5 μ or 8 to 13 μ	Thermal properties

The data resulting from such measurements should be analyzed to determine the optimum signal processing for detection of differences in moisture content. This analysis should be based on a large enough number of observations to be statistically significant, and sequential sampling may be necessary to insure such statistical validity. The number of environmental parameters that must be investigated may depend on the limitations which will be imposed on the operational system. A system operating well on clear, dry days may not function well at night or immediately after precipitation. Moreover, uniform target areas present different problems than variable target areas which may include several species of vegetation and various amounts of bare earth. Thus, the degree of operational versatility required will influence the planning of future research in this area.

REFERENCES

1. K. P. Davis, Forest Fire: Control and Use, McGraw-Hill, 1959.
2. G. M. Byram and G. M. Jemison, "Solar Radiation and Forest Fuel Moisture," J. Agr. Res., Vol. 67, 1943, pp. 149-176.
3. F. P. Weber, "Exploration of Changes in Reflected and Emitted Radiation Properties for Early Remote Detection of Tree Vigor Decline," Master's thesis, School of Natural Resources, The University of Michigan, Ann Arbor, 1965.
4. C. E. Olson Jr., "Accuracy of Land-Use Interpretation from Infrared Imagery in the 4.5-5.5 μ Range," Ann. Assoc. Am. Geographers, Vol. 57, 1967, pp. 383-388.
5. V. S. Shardakov, "New Field Method for the Determination of the Suction Pressure of Plants (in Russian)," Doklady Akad. Nauk SSR, Vol. 60, 1948, pp. 169-172.
6. C. E. Olson Jr., Spectral Reflectance Measurements Compared with Panchromatic and Infrared Aerial Photographs, Report No. 4864-8-T, Institute of Science and Technology, The University of Michigan, Ann Arbor, September 1964.
7. R. M. Hoffer and L. D. Miller, "Potential Applications of Remote Multispectral Sensing in Agriculture," presented at the Semi-Annual Meeting of the American Society of Photogrammetry, Dayton, Ohio, 24 September 1965.

WILLOW RUN LABORATORIES

DISTRIBUTION LIST

<u>Copy No.</u>	<u>Addressee</u>
1-25	United States Department of Agriculture Forest Service Washington, D. C. 20250 ATTN: R. M. Yates

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R&D		
(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)		
1. ORIGINATING ACTIVITY (Corporate author) Willow Run Laboratories, Institute of Science and Technology, The University of Michigan, Ann Arbor		2a. REPORT SECURITY CLASSIFICATION Unclassified
		2b. GROUP
3. REPORT TITLE OPTICAL SENSING OF THE MOISTURE CONTENT IN FINE FOREST FUELS		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Final Report, 18 April 1966 Through 22 January 1967		
5. AUTHOR(S) (Last name, first name, initial) Olson, Charles E., Jr.		
6. REPORT DATE May 1967	7a. TOTAL NO. OF PAGES viii + 22	7b. NO. OF REFS 7
8a. CONTRACT OR GRANT NO. U. S. Department of Agriculture Forest Service, Contract 13-220 b. ARPA Order No. 818 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) 8036-1-F 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
10. AVAILABILITY/LIMITATION NOTICES Distribution of this document is unlimited.		
11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Advanced Research Projects Agency, Department of Defense, Washington, D. C.	
13. ABSTRACT A preliminary study of the use of airborne remote sensors to determine the moisture content of fine forest fuels was performed. Laboratory and <u>in situ</u> measurements of light reflectance and energy emission from living and cut trees were obtained; the field data were collected during the 1966 growing season, while the laboratory measurements continued into early 1967. These data were then compared with multispectral imagery obtained over the test area in August and September 1966. For the first four days after cutting of the foliage, its reflectance increased at almost all wavelengths used, with the most significant increases occurring near 1.55, 2.05, and 2.50 μ . These increases seem directly related to decreasing moisture content, at least between moisture contents of 300% and 16% of the oven-dried weight of the foliar material. Radiometric data obtained were inconclusive, and problems with the multispectral sensors limited the validity of comparisons between the ground and airborne data. Nevertheless, it appears that multispectral imagery may provide useful information on the moisture content of fine forest fuels, and specific recommendations for additional work are included.		

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Multispectral imagery Remote sensing Forest fuels Vegetation characteristics Spectral reflectance and emittance Aerial surveillance						

INSTRUCTIONS

1. **ORIGINATING ACTIVITY:** Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization (*corporate author*) issuing the report.

2a. **REPORT SECURITY CLASSIFICATION:** Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. **GROUP:** Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. **REPORT TITLE:** Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. **DESCRIPTIVE NOTES:** If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. **AUTHOR(S):** Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. **REPORT DATE:** Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. **TOTAL NUMBER OF PAGES:** The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. **NUMBER OF REFERENCES:** Enter the total number of references cited in the report.

8a. **CONTRACT OR GRANT NUMBER:** If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. **PROJECT NUMBER:** Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. **ORIGINATOR'S REPORT NUMBER(S):** Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. **OTHER REPORT NUMBER(S):** If the report has been assigned any other report numbers (*either by the originator or by the sponsor*), also enter this number(s).

10. **AVAILABILITY/LIMITATION NOTICES:** Enter any limitations on further dissemination of the report, other than those

imposed by security classification, using standard statements such as:

- (1) "Qualified requesters may obtain copies of this report from DDC."
- (2) "Foreign announcement and dissemination of this report by DDC is not authorized."
- (3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through _____."
- (4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through _____."
- (5) "All distribution of this report is controlled. Qualified DDC users shall request through _____."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. **SUPPLEMENTARY NOTES:** Use for additional explanatory notes.

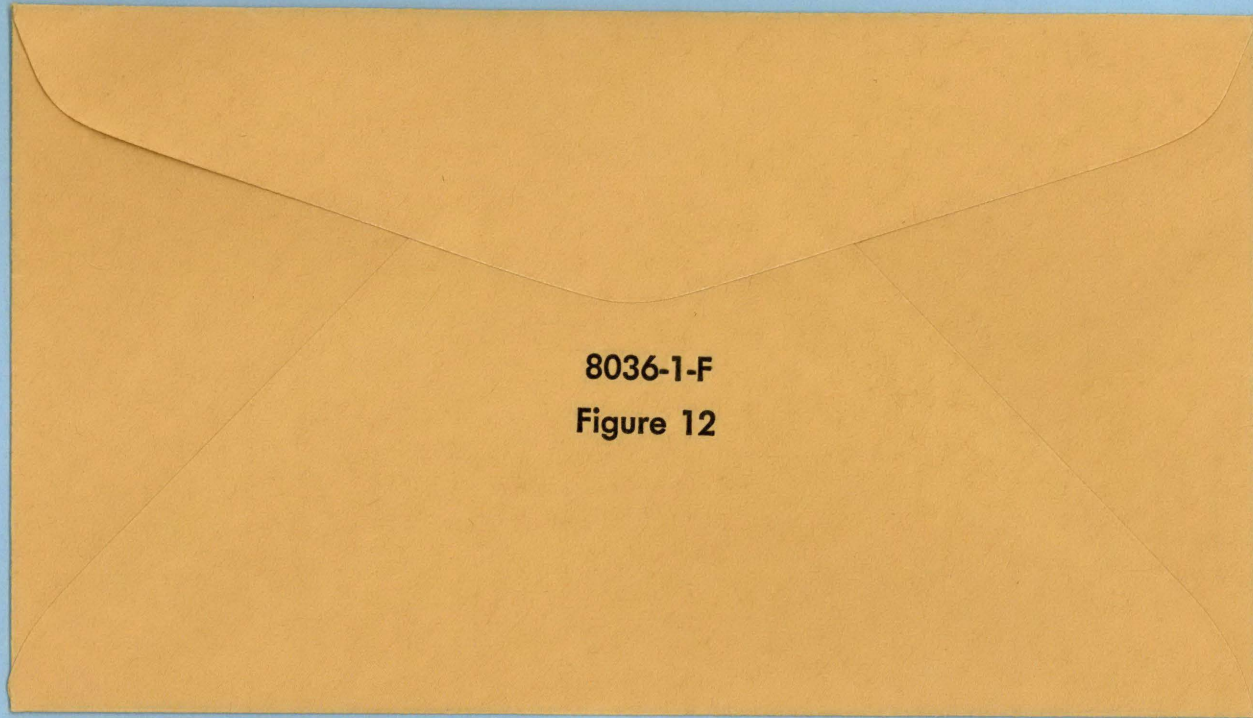
12. **SPONSORING MILITARY ACTIVITY:** Enter the name of the departmental project office or laboratory sponsoring (*paying for*) the research and development. Include address.

13. **ABSTRACT:** Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as (TS), (S), (C), or (U).

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. **KEY WORDS:** Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.



8036-1-F

Figure 12

